STATE OF CALIFORNIA
DEPARTMENT OF TRANSPORTATION
DIVISION OF CONSTRUCTION
OFFICE OF TRANSPORTATION LABORATORY

WATER-BASED CONCRETE CURING COMPOUNDS

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16. ABSTRACT

Proprietary water-based curing compounds were compared with solvent-based compounds now used by Caltrans. Water-based compounds protect concrete during the curing period as well as solvent-based compounds at a slightly lower cost.

A tentative specification for water-based curing compounds is included in this report.

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CONVERSION FACTORS

English to Metric System (SI) of Measurement

Quantity	English unit	Multiply by	To get metric equivalent
Length	inches (in)or(")	25.40	millimetres (mmm)
		.02540	metres (m)
	feet (ft)or(')	.3048	metres (m)
	miles (mi)	1.609	kilometres (km)
Area	square inches (in^2)	6.432×10^{-4}	square metres (m^2)
	square feet (ft^2)	.09290	square metres (m^2)
	acres	.4047	hectares (ha)
Volume	gallons (gal)	3.785	litres (l)
	cubic feet (ft^3)	.02832	cubic metres (m^3)
	cubic yards (yd^3)	.7646	cubic metres (m^3)
Volume/Time (Flow)	cubic feet per second (ft^3/s)	28.317	litres per second (l/s)
	gallons per minute (gal/min)	.06309	litres per second (l/s)
Mass	pounds (lb)	.4536	kilograms (kg)
Velocity	miles per hour (mph)	.4470	metres per second (m/s)
	feet per second (fps)	.3048	metres per second (m/s)
Acceleration	feet per second squared (ft/s^2)	.3048	metres per second squared (m/s^2)
	acceleration due to force of gravity (G)	9.807	metres per second squared (m/s^2)
Weight Density	pounds per cubic (lb/ft^3)	16.02	kilograms per cubic metre (kg/m^3)
Force	pounds (lbs)	4.448	newtons (N)
	kips (1000 lbs)	4448	newtons (N)
Thermal Energy	British thermal unit (BTU)	1055	joules (J)
Mechanical Energy	foot-pounds (ft-lb)	1.356	joules (J)
	foot-kips (ft-k)	1356	joules (J)
Bending Moment or Torque	inch-pounds (ft-lbs)	.1130	newton-metres (Nm)
	foot-pounds (ft-lbs)	1.356	newton-metres (Nm)
Pressure	pounds per square inch (psi)	6895	pascals (Pa)
	pounds per square foot (psf)	47.88	pascals (Pa)
Stress Intensity	kips per square inch square root inch (ksi $\sqrt{in}$)	1.0988	mega pascals $\sqrt{metre}$ (MPa $\sqrt{m}$)
	pounds per square inch square root inch (psi $\sqrt{in}$)	1.0988	kilo pascals $\sqrt{metre}$ (KPa $\sqrt{m}$)
Plane Angle	degrees (°)	0.0175	radians (rad)
Temperature	degrees fahrenheit (F)	$\frac{tF - 32}{1.8} = tC$	degrees celsius (°C)

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They also wish to thank members of the Transportation Laboratory staff from the Structural Materials, Soil Mechanics and Pavement, and Enviro-Chemical Branches who performed tests or assisted in obtaining materials needed for preparing test specimens.

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INTRODUCTION

Freshly placed portland cement concrete is subject to damage when winds, low relative humidity and elevated temperatures cause excessive evaporation of moisture from the surface layer of the concrete. Such damage may be avoided or reduced by providing a continuing supply of moisture or by applying a vapor barrier to exposed surfaces. Moisture for curing may be supplied via ponding, wet mats or fogging. Vapor barriers may be applied either as solid films of paper, plastic film, etc., or as liquids which dry to form solid films, e.g., concrete curing compounds.

The materials now used by Caltrans as curing compounds are essentially varnishes or paints. The vehicle portion is a solution or suspension of wax, drying oil, or resin in a volatile organic solvent. In situations where fresh concrete requires protection from hot sun, pigments are suspended in the vehicle. When it is desirable to retain the natural appearance of the concrete, e.g., with exposed aggregate, a clear vehicle or vehicle containing a fugitive dye may be used as a curing compound.

Two recent developments will cause the abandonment of the solvent-based types of curing compounds now specified by Caltrans. First, the use of volatile organic solvents in coatings will be severely restricted by air pollution control regulations. The Model Rule for Architectural Coatings, approved July 7, 1977, by the California Air Resources Board (CARB), limits volatile organic solvents in architectural coatings to a maximum of 250 grams per litre of coating (minus water) as applied. Concrete curing compounds are to be exempt from the ruling until September 2, 1982.

Since 1977 a number of CARB hearings have considered more or less restrictive regulations. Although the exact limits of the 1977 model rule may not be applied to concrete curing compounds, very similar regulations are expected to be enforced.

Secondly, volatile organic solvents may be expected to become increasingly costly and difficult to obtain as world petroleum resources become depleted. During a period of rising construction costs and tightening budgets, materials costs are very important. That is, the move to reduce volatile organic solvents content in compliance with air pollution control regulations will make economic sense.

This research project was initiated in 1979 to test curing compound formulations with low volatility and to develop specifications for their use by Caltrans. Formulations which would comply with the CARB guidelines could be 100% solids, high solids, or water-based materials. Both 100% solids and high solids coatings are expected to have higher material costs than either the solvent-based compounds now in use or water-based materials. Both 100% solids and high solids curing compounds would require costly modifications of application equipment and procedures. Water-based compounds are expected to be competitive with existing Caltrans specification curing compounds, and they can be applied using the equipment and procedures now in use on Caltrans projects.

Our 1979 literature survey indicated that, except for linseed-oil-based formulations, little work had been done to develop curing compounds with low volatile organic solvent contents. By writing to a number of curing compound manufacturers and paint raw materials suppliers, we obtained 23 samples of curing compounds for evaluation. Preliminary screening tests for conformance to CARB guidelines for low volatile organic solvent content and water retention test eliminated approximately two-thirds of the formulations submitted. Density, viscosity, drying time and freeze-thaw resistance tests were also performed to establish parameters for identification and quality control. Four satisfactory formulations, representative of the water-based types submitted for evaluation, were compared to solvent-based compounds for their influence on compressive strength, flexural strength and abrasion resistance of 3"x3"x11" concrete beams cured under laboratory conditions (73 ± 3°F, 50% relative humidity). They proved to be approximately equivalent in effect. A repetition of strength and abrasion resistance tests, performed using a 4'x6'x0.75' concrete slab under field conditions (70-90°F), demonstrated again the approximate equivalence of the water-based curing compounds to solvent-based curing compounds.

Using materials costs furnished by a curing compound manufacturer, we determined that, at the rates of application specified, the water-based curing compounds cost somewhat less to use than solvent-based compounds. A tentative performance type specification for water-based concrete curing compounds was written for use on Caltrans projects.

CONCLUSIONS

1. Water-based curing compounds can be used in lieu of solvent-based systems.

2. Water-based compounds are competitive in price with solvent-based products.

RECOMMENDATIONS

1. Caltrans should field test water-based curing compounds via contract change orders during the period when concrete curing compounds remain exempt from California Air Resources Board guidelines.

2. Caltrans should specify use of water-based curing compounds in Contract Special Provisions when exemption from California Air Resources Board guidelines ends.

3. Caltrans should develop compositional specifications for water-based curing compounds in order to reduce materials costs and to improve quality control.

IMPLEMENTATION

The specification for water-based concrete curing compounds developed on this research project has been submitted to the California Department of Transportation for use on highway construction projects. First use will occur in air pollution control districts which have set limits on volatile organic solvents in protective coatings.

TESTING

Literature Survey

A literature survey made in 1979 indicated that while curing compound formulations based on linseed oil have been evaluated and put into use, very little has been published about the evaluation or use of other types of curing compounds with low volatile organic solvents content.

Obtaining Samples for Testing

Letters explaining the project and requesting product samples were sent to 21 curing compound manufacturers and to 19 suppliers of paint raw materials. The lists of vendors included companies which have furnished such materials to Caltrans and others compiled from FHWA's Special Product Evaluation List.

Preliminary Screening Tests

It was originally intended to test proprietary curing compounds for desired characteristics, and later, follow raw materials manufacturer's recommendations to fabricate and test in-house formulations. Unfortunately, satisfactory proprietary curing compounds were submitted at a very slow pace, and there was insufficient time and manpower available for an in-house development program. Twenty-three proprietary curing compound formulations were screened for conformance to air pollution control regulations and for moisture retention efficiency over portland cement mortar blocks. In a few cases, a manufacturer reformulated his product one or more times in an effort to meet our preliminary requirements. Eight of the products tested met the CARB guidelines and also had satisfactory water retention characteristics. These results are shown in Table 1.

Other Laboratory Tests

During the period of the preliminary screening tests, the following properties of the curing compounds were also determined: density (lbs/gal), drying time, reflectance, viscosity and freeze/thaw resistance. While these properties should not be used as a basis for accepting one type of material in preference to another, they are useful in acceptance testing as indicators of quality control. Results of these tests are shown in Table 2.

TABLE 1

Proprietary Curing Compound Screening Tests

Product No.	Description*	CARB Guidelines Test[1]	Moisture Retention Test[2]
1	Pigmented Resin Emulsion	Fail	Pass
2	Clear Resin Emulsion	Fail	Fail
3	Clean Linseed Oil Emulsion	Pass	Pass
4	Pigmented Linseed Oil Emulsion	Pass	Pass
5	Emulsified Resin	Fail	Fail
6	Clear Water-Dispersed Linseed Oil	Pass	Pass
7	Clear Water-Reduced Alkyd	Pass	Pass
8	Pigmented Water Soluble Linseed Oil	Pass	Fail
9	Pigmented Water-Based Petroleum Hydrocarbon Resin	Fail	Pass
10	Clear Linseed Oil Emulsion	Pass	Pass
11	Clear Water-Based Resin	Fail	Fail
12	Pigmented Water-Based Resin	Pass	Fail
13	Clear Water-Based Resin	Pass	Fail
14	Pigmented Water-Based Resin	Pass	Fail
15	Clear Water-Based Resin-Wax	Pass	Not Tested[3]
16	Pigmented Water-Based Resin-Wax	Pass	Not Tested[3]
17	Pigmented Anionic Emulsion	Pass	Pass
18	Pigmented Nonionic Emulsion	Pass	Pass
19	Clear Resin Emulsion	Pass	Pass
20	Pigmented Emulsion	Fail	Pass
21	Water-Based Acrylic	Fail	Cracked & Flaked
22	Water-Based with some solvent) Not tested--contained		
23	Water-Based Emulsion) lumps and foamed severely		

1 Shall contain not more than 250 grams of volatile organic solvent per litre of finished compound, exluding water.

2 When tested in accordance with California Test Method No. 534, shall not lose more than 6 grams moisture in 24 hours.

3 Poor storage stability (product curdled).

*Manufacturer's terminology.

TABLE 2

Properties of Proprietary Concrete Curing Compounds

Compound No.	Description	Density Lb/Gal	Viscosity KU	Drying Time/Hrs		Freeze/Thaw Effect on Viscosity
				Set to Touch	Dry Through	
1	Pigmented Resin Emulsion	8.3-8.6	52-53	1/6-1	1/3-2	--
2	Clear Resin Emulsion	8.24	60	1	2	--
3	Clear Linseed Oil Emulsion	8.0-8.1	55-57	--	--	No change
4	Pigmented Linseed Oil Emulsion	8.5-8.8	57-59		Remained Tacky	--
5	Emulsified Resin	8.3	54	--	--	--
6	Clear Water-Dispersed Linseed oil	8.2	58	--	--	Reduced to 55-56 KU
7	Clear Water-Reduced Alkyd	8.4-8.5	61-63	1	--	Increased to 66-68 KU
8	Pigmented Water Soluble Linseed Oil	8.9	60	--	--	--
9	Pigmented Water-Based Petroleum Hydrocarbon Resin	8.3	59	3/4	--	Reduced to 55-56 KU
10	Clear Linseed Oil Emulsion	8.0	57	Over 24	Over 1 Week	Increased to 64 KU
11	Clear Water-Based Resin	8.1	66	1	Over 24	--
12	Pigmented Water-Based Resin	9.3	78	3	Over 24	Increased to 82 KU
13	Clear Water-Based Resin	8.3	Less than 49	--	--	Curdled
14	Pigmented Water-Based Resin	8.5	Less than 49	--	--	Curdled
15	Clear Water-Based Resin-Wax	8.3	Less than 49	--	--	Curdled
16	Pigmented Water-Based Resin-Wax	8.5	Less than 49	--	--	Curdled
17	Pigmented Anionic Emulsion	9.0	57	1	4	Increased to 60 KU Pigment settled, but was easy to redisperse
18	Pigmented Nonionic Emulsion	9.3	59	1	3	Increased to 61 KU
19	Clear Resin Emulsion	8.2	49	1/2	Remained Soft	Increased to 57 KU Formed gel which could be redispersed
20	Pigmented Resin Emulsion	8.5	50	1/2	Over 24	Increased to 59 KU Formed gel which could be redispersed
21	Water-Based Acrylic	8.5	55	1/6	2/3	--

Performance Tests on Concrete

In the Laboratory

After it had been demonstrated that water-based curing compounds can be made to meet both the Caltrans moisture retention test and the CARB guideline requirements, further tests were made. Four representative formulations were applied to 3"x3"x11" concrete specimens in the laboratory and compared to solvent-based petroleum hydrocarbon resin and chlorinated rubber curing compounds for their influence on strength and abrasion resistance. Untreated concrete specimens were included in the tests as controls. Curing conditions were 73±3°F, 50% relative humidity for seven days. All specimens treated with curing compounds had higher seven-day compressive and flexural strengths and sustained lower abrasion losses than untreated specimens. Each test result shown in Table 3 is the average of values determined for three test specimens. When applied to freshly cast concrete at a rate sufficient to pass the water retention test, water-based curing compounds have approximately the same influence on strength and abrasion resistance as solvent-based materials.

Under Field Conditions

Concrete placed on highway construction jobs is subject to more severe exposure conditions than were the 3"x3"x11" flexural beams in this project. We had hoped to set up an actual test section for comparing the performance of water-based curing compounds with that of solvent-based compounds now in use by Caltrans. Since we did not find a suitable project on which to perform the tests in hot weather, we

TABLE 3

Laboratory Tests of Proprietary Curing Compounds Applied to Concrete

Product No.	Description	Approximate Rate of Application (sq ft/gal)	Flexural Strength (psi @ 7 days)	Compressive Strength (psi @ 7 days)	Abrasion (grams)
		Round 1a - 7 sack concrete			
Control 1	Chlorinated Rubber, Solvent-Based	300	600	5340	14.3
Control 2	Petroleum Hydrocarbon Resin, Solvent-Based	200	600	5840	14.3
3	Clear Linseed Oil Emulsion	Unknown (poor application)	600	5760	7.0
6	Pigmented Linseed Oil Emulsion	200	570	5170	13.0
7	Clear Water-Reduced Alkyd	Unknown (poor application)	670	6030	14.7
		Round 1b - 8 sack concrete			
Control 1	Chlorinated Rubber, Solvent-Based	250	600	5260	13.3
Control 2	Petroleum Hydrocarbon Resin, Solvent-Based	200	670	5840	12.3
3	Clear Linseed Oil Emulsion	100	550	5760	13.7
6	Clear Water-Dispersed Linseed Oil	160	710	5170	11.7
7	Clear Water-Reduced Alkyd	100	510	6030	14.0

TABLE 3 (Continued)

Laboratory Tests of Proprietary Curing Compounds Applied to Concrete

Product No.	Description	Approximate Rate of Application (sq ft/gal)	Flexural Strength (psi @ 7 days)	Compressive Strength (psi @ 7 days)	Abrasion (grams)
		Round 2 - 8 sack concrete			
Control 1	Chlorinated Rubber, Solvent-Based	330	600	4810	13.7
Control 2	Petroleum Hydrocarbon Resin, Solvent-Based	210	600	5040	10.3
3	Clear Linseed Oil Emulsion	140	540	4710	--
		120	--	--	2.0
4	Pigmented Linseed Oil Emulsion	140	530	4520	--
		160	--	--	6.0
6	Clear Water-Dispersed Linseed Oil	100	580	4630	
		160	--	--	9.0
7	Clear Water-Reduced Alkyd	190	500	4550	10.3
		Round 3 - 8 sack concrete			
Control 1	Chlorinated Rubber Solvent-Based	250	600	4180	--
		330	--	--	14
Control 2	Petroleum Hydrocarbon Resin Solvent-Based	180	550	4220	--
		200	--	--	16
3	Clear Linseed Oil Emulsion	130	500	3900	9
4	Pigmented Linseed Oil Emulsion	170	480	3810	11

prepared an outdoor test slab using 6-sack portland cement concrete. The concrete mix design is shown in Table 4. The dimensions of the slab were 9'x4'x0.75'.

In this field condition test, three pigmented water-based curing compounds were compared with pigmented solvent-based petroleum hydrocarbon resin and chlorinated rubber curing compounds for their effects on the compressive strength and abrasion resistance of 6-sack portland cement concrete. Each compound was applied to a 4'x1.5' area, and a 4'x1.5' strip was left untreated as a control. After 14 days of curing outdoors at temperatures in the range of 70-90°F, six 4-inch diameter x 8-inch deep cores were taken from each strip. Three cores from each set were tested for compressive strength and three were tested for resistance to abrasion. All treated sections had significantly higher compressive strength and lower abrasion losses than the untreated section. There appeared to be no significant difference in performance among the five types of curing compounds. Test results are listed in Table 5. The plan view of the concrete slab in shown in Figure 1, and Figures 2 through 8 show the location of cores taken from each section for testing.

OTHER CONSIDERATIONS

The solvent-based and water-based curing compounds which were compared on the outdoor test on a 4'x9' concrete slab were all furnished by one supplier. The supplier also

TABLE 4

Concrete Mix Design for Outdoor Test Slab

Concrete Mix Design (6-sack mix, 0.5 water/cement ratio)

Water, lbs	283
Cement, lbs	564
Concrete sand, lbs	1269
1" x #4 coarse aggregate, lbs	1968

Aggregate Gradings

Sieve Size	Concrete Sand Percent Passing	1" x #4 Percent Passing
1-1 1/2"		100
1"		98
3/4"		78
1/2"		30
3/8"	100	12
#4	97	0.4
#8	84	
#16	66	
#30	40	
#50	20	
#100	6	
#200	2.3	

TABLE 5

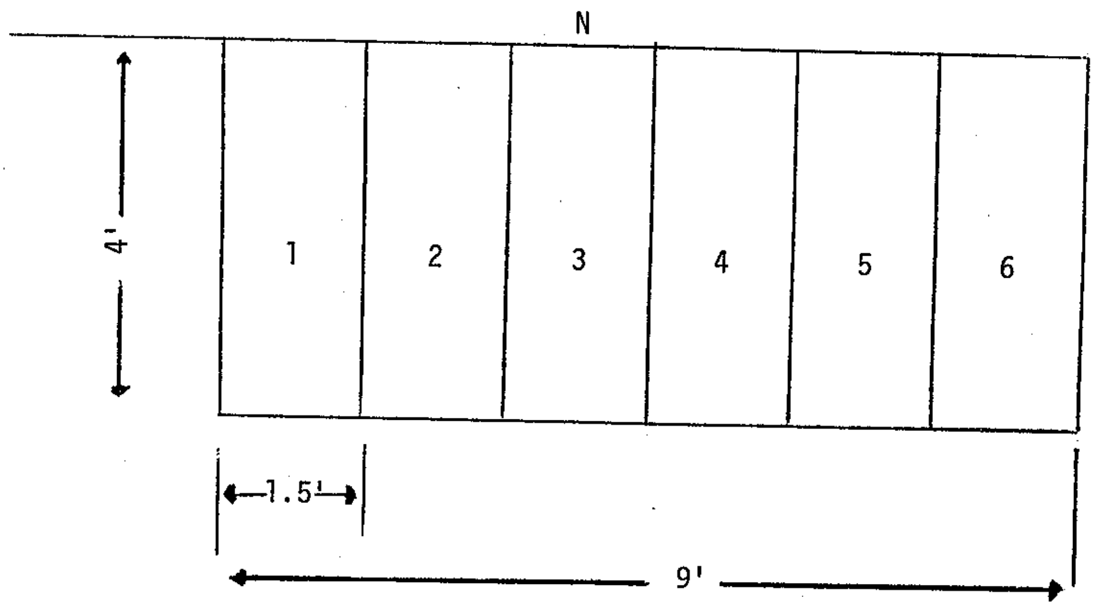
Performance Tests of Proprietary Curing Compounds Applied to Concrete Under Field Conditions (70°-90°F)

Section	Compound No.	Description	Rate of Application sq ft/gal	Compressive Strength* psi @ 14 days	Abrasion* loss, grams
1	Control 1	Chlorinated Rubber, Solvent-Based	300	4560	15
2	4	Pigmented Linseed Oil Emulsion	200	4470	13
3	17	Pigmented Anionic Emulsion	200	4625	14
4	Control 2	Petroleum Hydrocarbon Resin, Solvent-Based	200	4635	13
5	18	Pigmented Nonionic Emulsion	200	4690	15
6	Control 3	No Treatment	--	3845	28

*Average of 3 test specimens

FIGURE 1

PLAN OF CONCRETE TEST SLAB



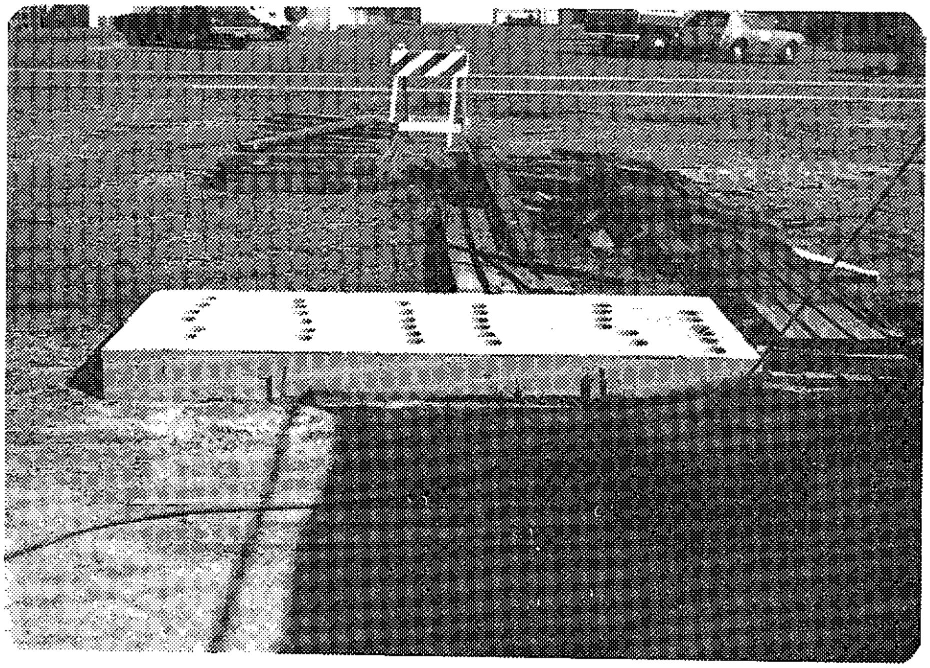


Figure 2

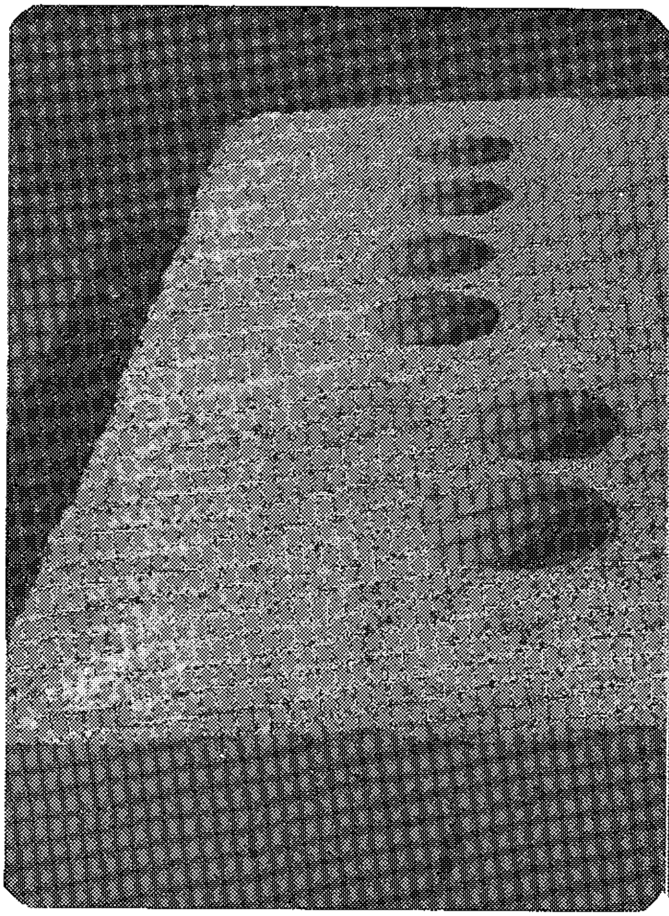


Figure 3

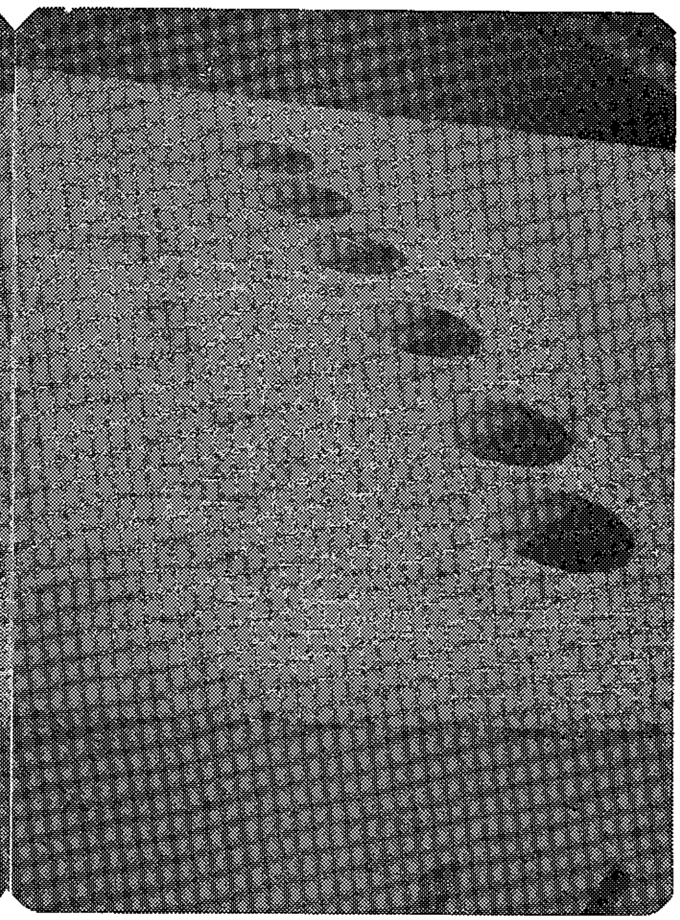


Figure 4

Views of Test Slab After Curing and Coring

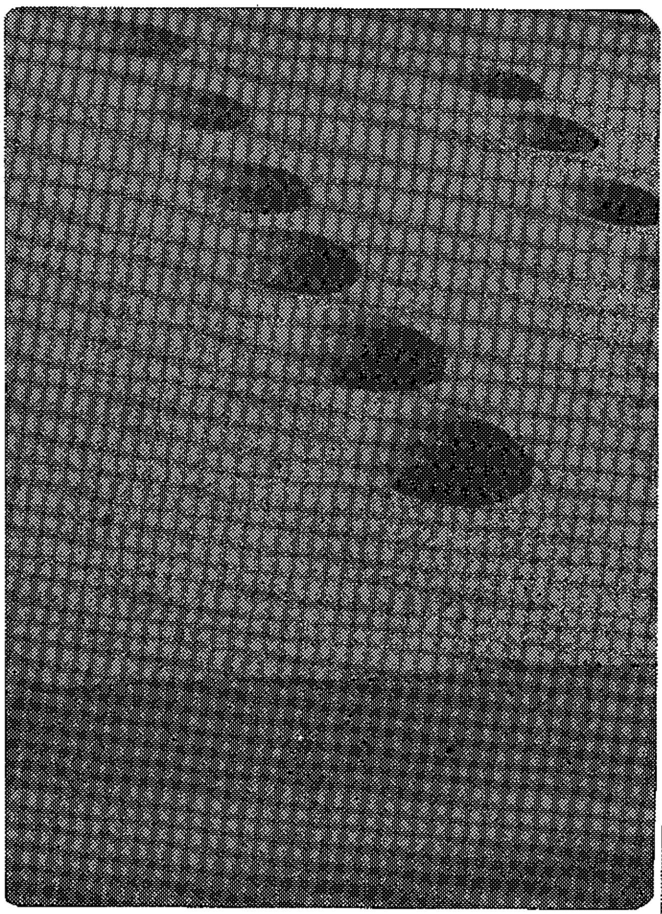


Figure 5

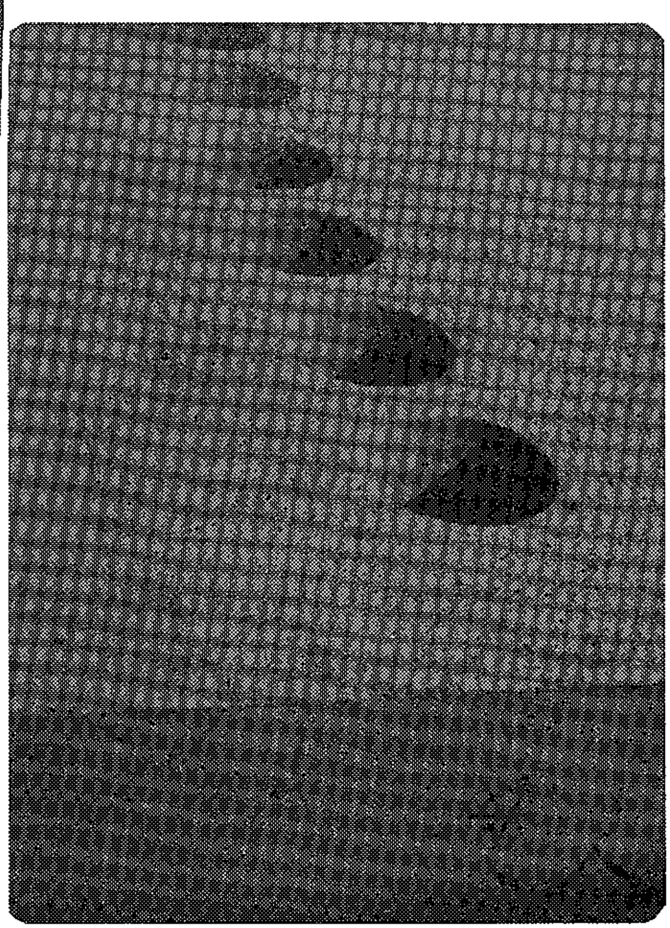


Figure 6

Views of Test Slab After Curing and Coring

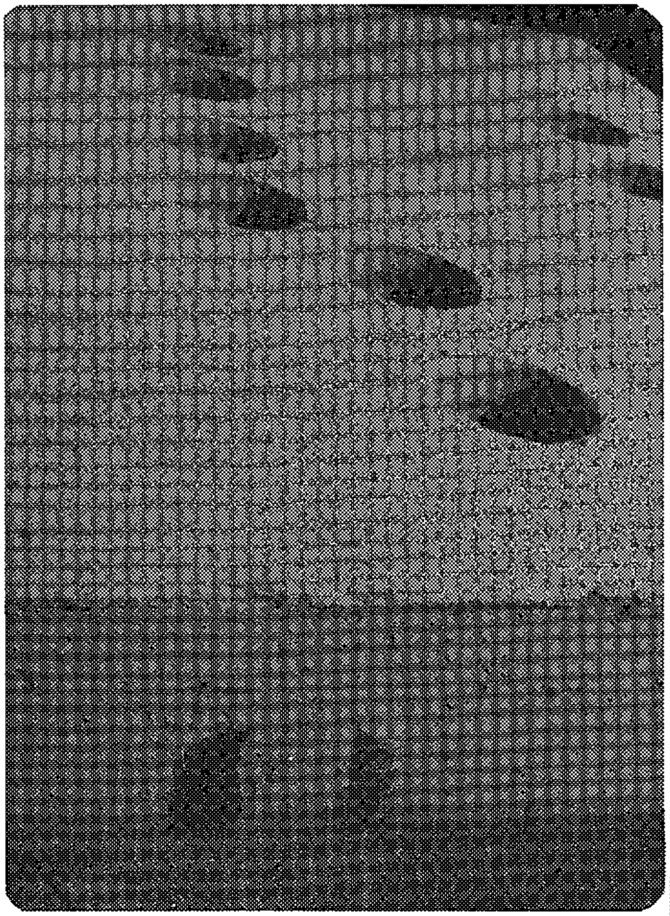


Figure 7

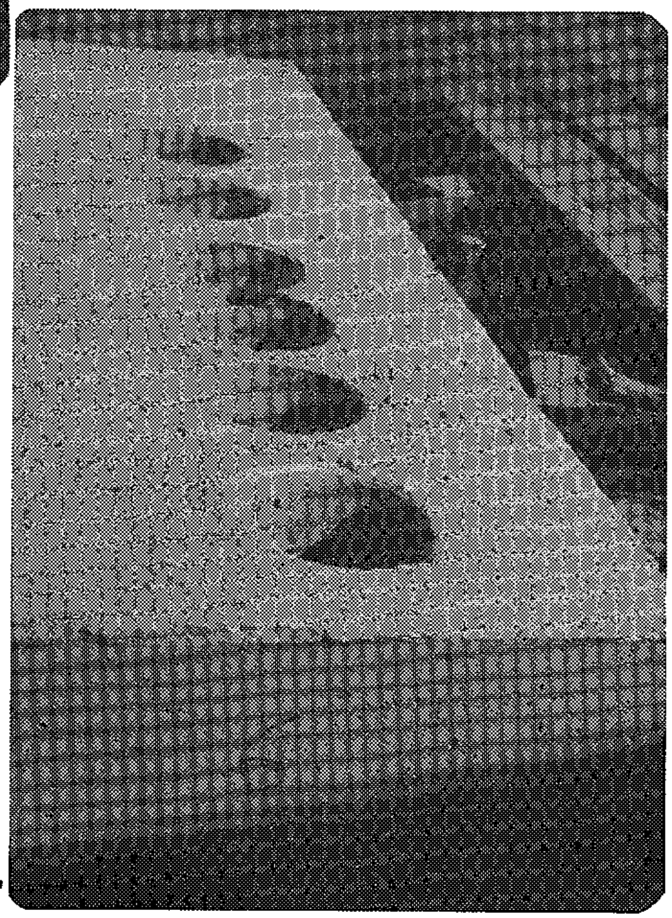


Figure 8

Views of Test Slab After Curing and Coring

submitted an estimate of the prices he would charge a distributor for furnishing each type of material in 55-gallon drums. The materials cost per gallon for the linseed oil emulsion curing compound was about 35% lower than that for the solvent-based petroleum hydrocarbon curing compound. The cost of the other water-based compounds was 5 to 8% lower, and the materials cost of the solvent-based chlorinated rubber curing compound was 60% higher. Since the chlorinated rubber compound is applied at the rate of 300 sq ft/gallon, while the other materials are applied at 200 sq ft/gallon, the materials cost as used is only 6% higher for chlorinatd rubber than for the petroleum hydrocarbon resin. The relative materials costs are shown in Table 6.

Since we were able to use the same equipment and procedure for applying all the compounds tested, it is apparent that use of water-based compounds will require no costly modifications from present methods.

Current Caltrans specifications require the use of the chlorinated rubber type curing compounds in situations, e.g., median barriers, where a durable weather-resistant paint-like coating is desired for aesthetic reasons. In general, water-based curing compounds may be expected to form coatings of the same durability as that of solvent-based compounds made from similar resins.

None of the water-based compounds tested under this project are as durable as chlorinated rubber. Water-based acrylic systems, which are costlier than other water-based material, may be expected to compare in durability with chlorinated rubber. To date, however, we have tested no acrylics which have suitable water retention characteristics.

TABLE 6

Estimated Relative Materials Cost of Solvent-Based and Water-Based Curing Compounds

Compound	Est. Cost/Gallon (Materials Cost)*	Est. Cost/Sq Ft (Materials Cost)	
		@ 200 sq ft/gal	@ 300 sq ft/gal
Petroleum Hydrocarbon Resin (solvent-based)	$5.80	$0.029	--
Anionic (water-based)	5.35	0.0268	--
Nonionic (water-based)	5.50	0.0275	--
Chlorinated Rubber (solvent-based)	9.25	0.0462	0.0308
Linseed Oil Emulsion (water-based)	3.66	0.0183	--

*Cost to the distributor when furnished in 55-gallon drums

SPECIFICATION DEVELOPMENT

Test values of curing compounds measured on this project were used in drafting a tentative specification for water-based curing compounds (see Appendix). Caltrans formulation specifications for solvent-based curing compounds allow minimum total solids contents of from 49.5 to 58.2%. Although water-based formulations are similar in properties to solvent-based formulations, it was decided to lower the total solids requirement to 35% minimum because one of the better performing water-based formulations contains only 36.5% total solids. Experience with both solvent-based and water-based formulations indicates that at least 7% pigment is required to meet the reflectance requirements in Caltrans, ASTM and AASHTO specifications.

The new viscosity requirement approximates that of the current solvent-based formulations. A lower limit on viscosity has been added to minimize drainage from sloping surfaces. Although the water retention characteristics now required of solvent-based curing compounds can be met by water-based formulations, the allowable water loss at 24 hours was increased from six grams to eight grams in order to conform more closely to the loss permitted by ASTM and AASHTO specifications which are familiar to manufacturers outside the State of California.

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APPENDIX

Tentative Specification for Pigmented Water-based Curing Compound

Pigmented curing compound shall be a water-based emulsion or suspension consisting of resins, latexes, or drying oils with co-solvents, pigments, extenders, suspending agents, and other additions as needed to obtain a product meeting all state and local air pollution control requirements in effect in California and having the following characteristics:

Total solids, by weight percent	35, minimum
Pigment, by weight, percent	7, minimum
Viscosity at 77°F, KU	50-65
Daylight reflectance, percent (ASTM: E97)	60, minimum
Water retention, grams net loss at 24 hrs-	8, maximum
grams net loss at 72 hrs-	23, maximum
Dry time at 77°F, 50% relative humidity, 6 mil wet film thickness-	
Set to touch, hours	1 maximum
Dry through, hours	4 maximum
Freeze-thaw resistance, ASTM-D2243, change in viscosity after freeze-thaw cycling, percent of original KU	10 maximum

The vehicle solids shall be organic materials; inorganic film-forming materials, such as silicates, will not be acceptable,